Dr. Nafe

Columbia University in the City of New York

LAMONT GEOLOGICAL OBSERVATORY
PALISADES, NEW YORK

DIRECT CURRENT MEASUREMENTS AND HYDROGRAPHIC OBSERVATIONS IN THE CARIBBEAN-ANTILLEAN REGION

Part I

Background and Plan of Research

Part II

Experimental Procedures and Field Work

R/V CONRAD Cruise 7, Leg 3

Prepared by: Robert Gerard

Technical Report No. CU-5-63 to the Atomic Energy Commission
Contract AT(30-1) 2663

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PART I

Background and Plan of Research

In the summer of 1885 Lt. J. E. Pillsbury, aboard the Steamer BLAKE, began some of the most important measurements in modern oceanography. Pillsbury, working for the Coast and Geodetic Survey, had devised during the previous year an ingenious current meter and an anchoring system for performing anchored current meter stations. During this first season of his research Pillsbury made observations at twelve anchored stations in the Florida Current in order to gain a quantitative understanding of the Gulf Stream, which had been known to mariners in its surface expression from the earliest time and had been first discussed scientifically by Benjamin Franklin. In subsequent years Pillsbury, using the Steamer BLAKE and improving his anchoring and current measurement techniques, continued to study the Florida Current in the Straits of Florida and began to examine some of the more distant sources of the Gulf Stream. In 1887, reasoning upon the temperatures and depths in the Gulf of Mexico and in the Caribbean passages, he extended his current measurements into the Gulf of Mexico and across the Yucatan Straits, as well as northward in the region of Cape Hatteras. During 1888 and 1889 this work was continued farther south in order to examine the origins of the waters entering into the Gulf Stream system, and measurements were made at about thirty-nine stations in the passages of the eastern Caribbean and in the Atlantic outside the island arc. These reports (Pillsbury, 1885, 1886, 1887, 1890 and 1891) form one of the early classical studies in modern oceanography. Of chief concern to the present project are those measurements made by Pillsbury during 1888 and 1889 in the eastern Caribbean and Antillean region. His measurements in this area are summarized in Figure 1, modified after Model (1950). The station locations are indicated in Figure 2.

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The next major studies of the Caribbean circulation were based upon the results of two cruises of the R/V ATLANTIS in 1933 and 1934. These results were presented chiefly by Parr (1937 and 1938), covering the descriptive results of the hydrographic stations, and by Parr (1937a) in a limited discussion of the dynamics of water movement derived from the hydrographic station data. A further discussion of the oxygen distribution and some interpretations, with regard to renewal of the Caribbean basins, was presented by Seiwell (1938). Deitrich (1939) summarized this work and added his interpretation of the sill depths of the deeper passages, over which deep-water exchange occurs between the Atlantic and the Caribbean basins. From these studies a general picture of the stratification through the Caribbean basins was obtained, and some indication as to the sources of the water masses present was indicated. The surface levels were shown to be a mixture of north and south Atlantic water. A considerable amount of Antarctic intermediate water was present in the salinity minimum level about 800 meters deep. Below 1200 meters distribution of temperature, salinity and density was shown to be remarkably uniform throughout the basins of the Caribbean. From the uniformity of the deep values it was believed that the replenishment of deeper Caribbean water took place over the various sills from the Atlantic deep water bounding the basins on the east and north. On the Atlantic side, water below the sill depths of about 1800 meters was shown to be denser than the Caribbean water at the same levels. The renewal of the deep water was believed responsible for renewal of the Caribbean deep water, but no estimates for the deep circulation were available from these studies. One later estimate of the renewal of the deep water in the Caribbean basins was that of Worthington (1955), who proposed that the refilling of the deep water was a periodic process, the last occurrence of which was estimated to have taken place at the end of the eighteenth century.

These calculations were based entirely on the apparent depletion of oxygen throughout all of the deeper levels from the measurements made in the early 1930's as compared to later determinations made two decades later.

Increased numbers of hydrographic measurements in the Caribbean region since the International Geophysical Year have enabled more extensive studies to be made in the Antillean-Caribbean region. Wüst (1962) has presented an outline of a new interpretation of the deep circulation, based upon approximately 2000 hydrographic stations. These data, together with improved and enlarged topographic information, have provided sufficient material for application of the well-known core method. Core charts of the chief sub-surface layers have been prepared, and a complete discussion of these results is in press (Wüst, 1963), as part of the work of the present contract.

Concurrent with the core studies, calculations of the geostrophic current across sections perpendicular to the axes of current flow indicated by the core method are being prepared. To supplement the dynamic computations and the core-method interpretations, a program of direct current measurements in certain key regions of the Caribbean has been planned, to be carried out aboard the R/V CONRAD during August and September, 1963. Because of the limited time available to the direct current measurement survey, only three areas have been chosen for the placement of current meters and current measuring apparatus. Figure 3 shows the proposed locations of anchored current meter buoy stations. The first area to be visited will be in the passages north and south of the island of St. Lucia. It is proposed that three anchored current-meter buoys be placed across each of these passages to record for approximately two weeks. The levels selected are roughly the same for each passage and are considered a minimum necessary for a reasonable interpretation of the currents and volume transport through these passages. Table I lists

the levels at which current meters will be placed in this area.

TABLE I.

Current Meter Placement in North and South St. Lucia Passages

Depth (meters)	Water Mass Characteristic
10	Surface water
100	Salinity maximum
650-700	Salinity minimum
950-1000	Deep water

In the second area in the eastern Venezuela Basin, locations have been chosen partly on the basis of preliminary dynamic computations, which indicate the most vigorous circulation in the upper 1000 meters, a condition which is also suggested by the core charts which have been prepared for the Wüst atlas. Here the placement of current meters will adhere to the following schedule, presented in Table II.

TABLE II.

Current Meter Placement in Eastern Venezuela Basin

Depth (meters)	Water Mass Characteristic
10	Surface water
150	Salinity maximum
700-800	Salinity minimum
1200	Reference level
2500	Deep water
3500-3800	Bottom water

In the third area in the region of the Virgin Island Passage, the depth of placement of recording current meters will be much the same as in the St. Lucia Passages, excepting that a near-bottom meter will be placed at a depth of about 1650 meters.

In addition to the long-period recording current meters to be placed on anchored-buoy arrays, it is planned to make drogue float measurements at approximately the same levels as have been listed for the placement of current meters. Besides these two techniques for current measurement, still another method, going back to the manner of Pillsbury, will be used. It is proposed to make anchored ship observations in some of the shallower areas, using an electrical current meter, lowered on a conducting cable, which will record on the ship's deck. This instrument will be used in preliminary measurements to determine the suitable levels for placing the long-period recording meters. It is also planned to use a photographic current meter while anchored. This device records bottom currents when placed on the ocean floor for short periods.

There follows a discussion of the technical aspects of the instrumentation which is proposed in the present field work.

Recording Current Meters

The meters which will be employed are somewhat similar to those described by Richardson (1962). These use the principal of a rotating Savonius rotor, which is magnetically coupled through the end cap of a heavy-walled aluminum pressure case to the internal registration mechanism, which indicates accumulated revolutions. Direction is obtained by a vane at the opposite end of the cylindrical pressure case, which is also magnetically coupled to a vane follower inside the pressure cylinder. A camera photographs (on a cycle of one frame each twenty minutes) the magnetic compass, vane follower, and accumulated revolutions dial, together with a tilt-angle meter, all in a single

picture. Differences in accumulated revolutions from frame to frame indicate the average current velocity during the interval between pictures. Camera recorders of this sort are capable of operating for periods of approximately three months. The current meter which will be employed at anchored-ship stations will be similar to that described, but in lieu of the camera recorder, the pulses representing individual rotations of the rotor and a DC voltage (the amplitude of which indicates current direction) will be used, together with suitable recorders on the ship's deck.

Parachute Drogue Floats

A simple and useful technique has been used to indicate the direction and velocity of subsurface currents by means of a parachute, which is opened at the depth of desired measurement and is connected by a fine wire to a surface buoy bearing some identifying marker and navigation aid for location by radar or visual sighting. We plan to use 35-foot diameter parachutes, together with 3/32-inch steel-wire rope connected to a styrofoam spar buoy, which will be fitted with flags, a flashing light, and a radar reflector for ship's tracking. In practice, the spar buoy is put over the side attached to one end of the steel-wire rope, and the boat steams slowly away, paying out wire while so doing. When an amount of wire equal to the depth at which the current measurement is to be made has been put out, the wire is cut and a terminal fitting applied. The parachute is then attached, together with about twenty-five pounds of weight, to this end of the wire. The parachute is allowed to settle slowly, opening as it does so, to a depth determined by the length of the wire. Experience has shown that the wire remains essentially vertical in almost every case, so that its length is a measure of the depth of placement of the parachute. The float at the surface is followed and its position checked periodically to the best of the available navigation. Its travel is

considered to represent the trajectory or stream flow at the level at which the parachute is opened. Computations for the drag of the components of such a system (Volkman, Knauss & Vine, 1956) indicate that the parachute accounts for more than 95% of the observed movement of the buoy at the surface and, therefore, may be considered a valid measurement of the current movement at depth.

Buoy System

Considerable experiment has gone into the design of a suitable deep-sea buoy and mooring system. Figure 4 illustrates a taut-line mooring using nylon rope as the buoy line. In the present survey a taut-line mooring will not be attempted in that it requires a considerable amount of anchor weight in order to load the nylon line so that it will stretch some 15-20%. Instead, about a one-to-one ratio of nylon rope to ocean depth will be used, and a single bundle of two or three cast-iron cubes, weighing 500 pounds each, will be used for anchoring. In placing such a buoy system with current meters, the following procedures are followed. The buoy with its chain bridle and surface instrumentation, consisting of a recording anemometer, buoy light and radar reflector, is placed in the water, and the anchor line is paid out from the ship, which moves slowly away from the buoy. At selected intervals the line is terminated, and current meters are inserted in the line by means of shackles and ball-bearing swivels. The use of ball-bearing swivels is considered paramount in obtaining reliable data from the current meters, which are placed in series in the line. This is because any rotary motion of the current-meter casing will be recorded as an addition to the apparent rotation of the rotor and will cause apparent instability in the direction vane record. In addition to this precaution against rotation of the meter case, a large fin is placed on the outside of the meter to insure against rotation. When a suf-

ficient amount of line has been placed in the water, the ground tackle, consisting of chain and iron cubes, is secured to the terminus of the line, and the anchor package is jettisoned, using a small sea anchor on the lowermost anchor weight to prevent tumbling of the heavy weights in their fall through the water. It has been the experience of some observers that curious breaks in the upper portion of the synthetic rope have occurred, which are believed to be from biting fish. As a precaution against this, in the upper lengths of our line we propose to use steel-wire rope for the upper two-hundred meters. The wire rope of 1/4-inch diameter will have the added benefit of lower drag than the remainder of the anchor line in the upper-water levels where the highest velocities may be expected. The nylon line, making up the remainder of the anchor line, is of 1/2-inch diameter. Great care must be taken in handling the synthetic line to avoid abrasion and chafing. In addition to providing chafe-free thimbles at the terminals of the nylon-line segments, synthetic line, being smooth and slippery, must have eye-splices at its terminals, which are carefully prepared. Eye-splices using the following technique have been used: Five regular tucks are taken, then the three strands are split and recombined with adjacent strands, and five more tucks are made. The entire splice is then put under about 1000-pounds tension, and the base of the splice with the projecting strands is tightly served with marline. These techniques and precautions have served well in past experience in preparing deep-sea buoys.

Buoy Line

Several recent reports are available on the characteristics of deep-sea moorings (Wilson, 1962; Beck, 1962; Isaacs et al., 1963). These studies have compared the strength, weight, and drag characteristics for different arrays. In the end it would appear that nylon has the most desirable qualities of

strength, weight, freedom from flow under stress, elasticity, and general serviceability. Considering a two-layered ocean from the standpoint of current velocities, the following Table III represents fairly realistic design parameters.

TABLE III.

Velocity in knots

Layer	1 Open Ocean	2 Channel	3 Gulf Stream
0-4000 ft.	1	2	4
4000-12,000 ft.	.5	1	2

The following Table IV gives current load in pounds on various line diameters, assuming them to be in the above-mentioned two-layered system to 12,000 foot depths with the lines perpendicular to the direction of the current. These calculations have been made using the formulae found in Wilson (1962).

TABLE IV.

Strain for 12,000 foot depths

Line diameter (inches)	Calculated pounds tension in current perpendicular to configuration		
	1	2	3
3/16	304	1215	4860
1/4	405	1620	6480
5/16	506	2025	8100
3/8	607	2430	9720
7/16	709	2835	11340
1/2	810	3240	12960
9/16	912	3650	14597

Considering the expectable currents in the Caribbean, it would appear that condition #2 serves as a conservative estimate around which to design a mooring system. Using computations such as this, 1/2-inch nylon line with neutral buoyancy in sea water was selected.

PART II.

Experimental Procedures and Field Work

R/V CONRAD Cruise 7, Leg 3

August 13 - September 20, 1963

On August 13, 1963 the research vessel CONRAD departed from Fort de France, Martinique to begin the field program outlined in Part I of this report. At the outset it was apparent that certain modifications of the original proposal would be necessary due to the fact that certain units of the ship's equipment were not functioning. It should be stated that the R/V CONRAD, the first of a new GOR (General Oceanographic Research) class built by Bureau of Ships, U. S. Navy, was delivered to Lamont Geological Observatory in November 1962. At the time of this research cruise the ship had been operating less than one year, and its final acceptance trials had not been completed. Expectably, a number of deficiencies developed during this first year of operation, and to some extent these deficiencies made it impossible to carry out the full plan of research on this project. In particular, during the first part of this cruise in the month of August, a breakdown in the ship's fresh water equipment made it necessary for a number of returns to Fort de France to replenish fresh water, which had not been anticipated in our initial cruise plan.

A number of preliminary placement charts and drawings have been prepared to show the distribution and location of the most important observations which were made during this cruise. Figure 5 illustrates the location of 28 hydro-

graphic stations taken in the passages and the deeper water areas, where direct measurements of current were obtained. These hydrographic stations, including observations of salinity, temperature, and oxygen, were taken serially from the surface to the bottom at standard depth intervals, and in many cases were more closely spaced than the standard recommended depths. Figure 6 illustrates the location of eight anchored stations, where direct current measurements and other observations were obtained. Figure 7 shows the location of the anchored current meter arrays, two in the passages and two in the Venezuela Basin. Figures 8 and 9 show the location and the approximate movement of drogue buoys in the passages and in the southern Venezuela Basin. Tables V and VI tabulate the generalized data pertinent to these drogue observations.

The R/V CONRAD departed from Fort de France at noon on August 13 and made for the Central St. Lucia Channel position. Along this track sub-bottom profiling was accomplished using half-pound TNT charges, and bottom echo-sounding and continuous magnetic records were obtained. A dense network of echo soundings through the St. Lucia Passage was accomplished in order to determine the precise sill depth location for placement of our anchored current meter array. The topographic data were quickly worked up in order that the sill characteristics could be known, and an anchored station was made at the position of the sill in approximately 522 fathoms depth.

At this anchor station and at a total of eight anchor stations occupied during the course of this research, the following system was used. The ship maintained its position as well as possible at the location selected for the anchor station. With the stern pointed against the direction of the set, the 1/2-inch diameter steel wire rope, used normally in the coring and trawling operations, was lowered from the A-frame, using the coring winch. At the

TABLE V.

Parachute Drogues in St. Lucia and St. Vincent Passages

Drogue Number	Date	Placement Depth (Meters)	Period of Observations (Hours)	Generalized Direction T	Velocity Kts.
1	Aug. 30-Sept. 1	10	44	279°	.57
2	Aug. 30-Sept. 1	65	47.5	259°	.45
3	Aug. 31	325	9.5	291°	.40
4	Sept. 1 - 2	600	32.5	258°	.34
5	Sept. 5 - 6	685	7	357°	.70
6	Sept. 5 - 7	137	34	329° then 267°	.92
7	Sept. 5 - 7	10	34.5	310° then 257°	1.10
8	Sept. 6 - 7	550	17.5	299°	.66

TABLE VI.

Parachute Drogues in Southern Venezuela Basin

Drogue Number	Date	Placement Depth (Meters)	Period of Observation (Hours)	Generalized Direction T	Velocity Kts.
9	Sept. 12 - 14	800	31	306°	.74
10	Sept. 12 - 14	150	34	315°	.77
11	Sept. 12 - 14	10	27	323°	1.15
12	Sept. 14 - 16	2500	37.5	286°	.17
13	Sept. 14 - 16	1250	38	283°	.26

terminus of this wire attachment was made to approximately ten meters of 1/2-inch chain. The chain was shackled to a 500 pound cast-iron cube, which, in turn, was attached to a second ten meter length of chain at the bottom of which was shackled a 300 pound Danforth anchor. This tackle was lowered to the bottom, and bottom contact was clearly seen on the winch tensiometer. At this point in the operation the ship's propulsion, used to maintain position, was cut off, and the ship was allowed to drift while the core-winch wire was slowly paid out. This was continued until a scope of approximately two-to-one with the bottom depth was achieved. At this stage the winch was secured, and the tensiometer was carefully observed as the ship's drift took up the wire slack. By observing the tensiometer one can readily see at which point the anchor is solidly holding on the bottom; and where this was not immediately achieved with a two-to-one scope, additional wire was paid out until a maximum of three-to-one scope, in some cases, was reached. When the ship had reached equilibrium with the sea conditions and its anchor scope, other operations, such as current meter lowerings, commenced. As a precaution against excessive wear at the sheaves leading the anchoring wire out over the ship's side, a few fathoms of wire were let out every couple of hours during the anchor station. Radar ranges and bearings were taken hourly during each anchor station from nearby islands to determine any possible drift during the anchor station.

At anchor station #1 five lowerings were made, using a deck-recording Savonius rotor current meter lowered on our conducting hydrographic wire. Recordings of velocity and direction were made at eighteen levels from the surface to the bottom, both lowering and raising the instrument. These observations were conducted over a twenty-four hour period. At this same location a hydrographic station was made, and two large-volume water samples for isotope analysis were collected. In addition, one biological station was made.

Following the anchor station, which was completed August 15, an anchored current meter array was set consisting of a surface buoy and five current meters, extending from the surface to the bottom. An anchor consisting of two 500 pound cubes of cast-iron was used in this array. Shortage of fresh water at this time necessitated immediate return to Fort de France, and thus the period of observation of the anchored array was limited to only about two hours. The ship returned to Fort de France on August 16 to replenish water and attend to other maintenance and personnel matters.

On August 19 the R/V CONRAD returned to the area of the Central St. Lucia Channel to find that the anchored buoy was missing, having apparently broken away. A search pattern was laid out in the expectable direction of drift, and a search was carried out to the westward of the original position until the following day. During this search continuous seismic profiling and other underway observations were carried out. The search was unsuccessful, and no parts of the initial buoy array were recovered. It was unfortunate that the ship could not operate in the passage following the placing of this buoy, as originally planned. In such case it would have been possible at least to recover the floating gear and determine the cause of the failure. As it happened, no information was gained as to the loss of the buoy array.

On August 20 an anchored buoy array was prepared and set in the same place on the sill in the St. Lucia Passage. This is shown as buoy #1, Figure 7. The array contained four long-period photographic recording current meters. It differed from buoy #1A only in that three 500 pound anchors were used instead of two. The three cast-iron cubes were separated by ten meter lengths of 1/2-inch chain. The buoy and anchor system was essentially the same as that described in Part I of this report, except that it was not set out as a taut-line system. Instead, the nylon rope lengths were cut so that

the total length of line should be the same as the ocean depth, rather than a percentage smaller, as is the case with the taut-line system. Figure 10 is a photograph which illustrates the method of placement of the current meter in the buoy anchor line. The photograph shows the heavy ball-bearing swivels which are used above and below the meter, and the large plywood fin, which is attached to the meter case in order to prevent rotation which would falsify both the velocity and direction readings. The array was set in the following manner. The toroid buoy, equipped with radar reflectors and a flashing light, was first set out; and the ship was moved slowly in the direction of the surface current, paying out the anchor line aft of the ship. At predetermined intervals the current meters were attached to the anchor line and lowered horizontally with recoverable guy-lines from the ship's rail, so that they would be placed gently in the water. The line was paid out under moderate tension at all times in order to keep the array stretched out to avoid entanglement of the meters and the nylon line. In all cases 9/16-inch three-strand nylon rope was used in the anchor line, excepting for the top one-hundred meters, which was made up of 1/4-inch stainless steel wire rope. The upper link of wire rope was provided in order to avoid the hazard of fish bites, as referred to in Part I of this report. One result of using wire rope in the upper link of this anchor line was that extensive corrosion developed on the unprotected steel parts (thimbles, shackles, etc.) due to the use of dissimilar metals and possibly due to the action of a cell resulting from a strong gradient in the dissolved oxygen concentration in the top one-hundred meters of the ocean.

After the placement of buoy #1, anchor stations #2 and #3 were occupied in the St. Lucia Channel, and deck-recording current meter readings were made at each station over a twenty-four hour period in addition to taking hydro-

graphic stations at each place and obtaining bottom camera current meter observations. The deck-recording current meter uses a Savonius rotor and direction vane similar to the photographic recording current meter. However, the signal, consisting of electrical pulses and a voltage of changing amplitude, is sent up the electric hydrographic wire to the ship's deck, where recording in the laboratory is made at the levels at which the meter is stopped. The depth of the meter, during all of our experiments, was monitored in two ways, first by the wire length recorded from the meter wheel, and secondly using an acoustical pinger. The pinger sound pulse is received directly on the ship's echo sounder; the echo from the ocean bottom is also received after a delay indicating the depth above bottom. In all cases the echo depth and the wire meter depth were in close agreement. A lead weight of approximately 750 pounds was used beneath the current meter in order to maintain a straight wire, even though the currents near the surface were at times in excess of one knot. The record obtained from the deck-recording current meter is illustrated in Figure 11. On the left the straight line centered on the chart scale indicates a current from the south, the entire chart scale being linearly divided through 360 degrees. The scale on the right contains the velocity information, which can be read as two pulses per revolution of the Savonius rotor against a chart transport rate of five millimeters per second. The rpm information is then read on a graph of rpm versus velocity, which has been prepared for the Savonius rotor. In addition to this work, large-volume water samples for isotope analysis were obtained in the surface water, and plankton samples were obtained at both stations.

Between August 25 and September 2 work was done first in the St. Vincent Channel. Prior to making our stations, a dense network of echo-sounder crossings was made with radar control from the nearby islands. This provided

precise topographic information for the placement of stations. An anchored buoy array with four meters was placed on August 26. The set-up and procedures followed were similar to those employed for buoy #1. Following this, three anchored current stations were occupied for about twenty-four hours each. At these stations deck-recording current meter lowerings were made, hydrographic stations were taken, and bottom camera current meter observations were also made. Following the work in the St. Vincent Channel, the ship returned to the St. Lucia Channel for several days of parachute drogue observations. Along the track from the northern to the southern work area seismic reflection profiling was continuously done, and at a number of locations on the Atlantic side of the island arc hydrographic stations were taken at approximately twenty-mile intervals.

From September 4 until September 8 hydrographic stations were made in the area to the west of the island arc in the Caribbean Basin, and parachute drogue measurements were accomplished in the St. Lucia Passage and the St. Vincent Passage. These drogue observations are illustrated in Figure 8 and summarized in Table V. In these operations thirty-five foot diameter parachutes were used, suspended from 3/32-inch diameter steel wire rope, which was attached at the surface to a spar buoy float fitted with radar reflectors, flashing lights and coded flags. The lengths of wire rope were cut so that the weighted parachutes would reach a selected depth (roughly comparable to the wire length) and behave under the influence of the current at that depth. With this system it is assumed that the drag at the parachute is far in excess of that created by the fine wire and the surface spar buoy, and, therefore, will reveal the current velocity and direction at the depth of the parachute with only a small correction required for the drag associated with the other parts of the system. Volkman, Knauss, and Vine (1956) have studied the be-

havior of parachute drogues, and their formula for drag correction will be used in processing these data. Of chief concern in the use of subsurface parachute drogues is the determination of the actual depth of the parachute when the system has reached equilibrium. In most cases it is assumed that the wire length does, in fact, indicate the depth of the parachute. To test this, acoustical pingers were placed on several of the deeper parachutes, and these were monitored with the ship's echo sounder in order to examine the difference between wire length and actual depth of the parachute under various conditions. In some cases differences in wire length and acoustic depth, amounting to about 20%, were observed. These measurements will be used to interpret and correct the drogue data.

The system used in placing the parachute drogues was similar to that used in placing anchored buoys, in that the spar buoy was placed in the water first, and the wire rope was paid out as the ship was moved away at slow speed. The parachute was fixed to the terminus of the wire, placed in the water in the open position, and allowed to settle slowly, using approximately fifty pounds of weight to carry the parachute to its ultimate depth. Where pingers were used, a weak link was employed in order to break away the parachute so that the pinger could be quickly hauled to the surface for recovery at the end of the experiment. All drogue experiments were carried out over periods of at least twenty-four hours.

After completion of work in the St. Lucia - St. Vincent area the ship moved west to the southern Venezuela Basin. On the track from the island arc to the deep-basin area seismic reflection profiling was accomplished, and bottom sediment cores and bottom camera stations were taken. Two anchored buoy current meter arrays were placed in this basin in depths of about 4000 meters, as indicated in Figure 7 . Hydrographic stations were taken at

twenty-mile intervals, spaced along a north-south line at approximately 64°30' West (Figure 5). At the place of the southernmost anchored buoy in this area parachute drogue measurements were accomplished as indicated in Figure 9 and summarized in Table VI.

One bottom camera current meter station was made near the northern buoy. The operation of the bottom camera current meter in this and other stations, shown on Figure 7, consisted of lowering to the ocean bottom a modified Lamont underwater camera set within a heavy tripod frame. On the same frame and within the camera field, sensors for current velocity and direction were photographed at intervals of about thirty seconds while the rig rested on the ocean bottom for a maximum of thirty minutes. The sensors consisted of three light-weight pendulums on a horizontal plane, set at 120 degrees apart so that current velocity from any direction could be read proportionate to the deflection of one or more of the pendulums. In the field of each frame can also be seen a magnetic compass and a direction vane, which indicate the direction of current. Figure 12 illustrates a plot of direction and velocity read from a bottom camera current meter record obtained in the St. Lucia Channel during CONRAD Cruise #5.

The work in this area was concluded on September 17, and the ship moved north to the Virgin Passage area, where two anchored stations were made on September 18 and 19. At each of these positions (Figure 7) the deck-recording current meter was lowered to the bottom, and the bottom photographic current meter was also used. One surface parachute drogue measurement was made (Figure 13, Table VII). In addition, large-volume isotope water samples were obtained, and biological stations were made. The work concluded with landing at St. Thomas on September 20.

TABLE VII.

Parachute Drogue at Anchor Station #7.

Drogue Number	Date	Placement Depth (Meters)	Period of Observations (Hours)	Generalized Direction T	Velocity (Kts.)
14	Sept. 18-19	30-50	16	223°	.28

Since the conclusion of the field work, processing of the data obtained has been in progress at the Laboratory in the following areas:

1. Correction of hydrographic station measurements, including recalibration and ice-point check of reversing thermometers;
2. Reading of current meter film records of two types:
    a. The long-period recording current meter films (16 mm.),
    b. The bottom camera current meter films (35 mm.);
3. Analysis of the deck-recording current meter records;
4. Plotting of detailed topography in the area of the St. Lucia Channel Sill and the St. Vincent Channel Sill.

The first volume of studies on the "Stratification and circulation in the Antillean-Caribbean basins", together with an oceanographic atlas, is now in the hands of the printer; and the dynamic computations for the second volume of this series have been completed. It is planned that the direct current measurements resulting from this field research will be incorporated into the second volume of this series, to be published early in 1964.

FIGURES AND TABLES

Figures

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2. Current meter stations, "BLAKE" 1888-1889
3. Positions of proposed anchored current meter stations
4. Taut-line mooring system
5. Positions of CONRAD #7 hydrographic stations
6. CONRAD #7 anchor stations and table of observations
7. CONRAD #7 anchored buoys with current meter arrays
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10. Photograph of current meter placement in buoy anchor line
11. Sample of record from deck-recording current meter
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13. Parachute drogue at anchor station #7

Tables

I. Proposed current meter placement in North and South St. Lucia Passages

II. Proposed current meter placement in Eastern Venezuela Basin

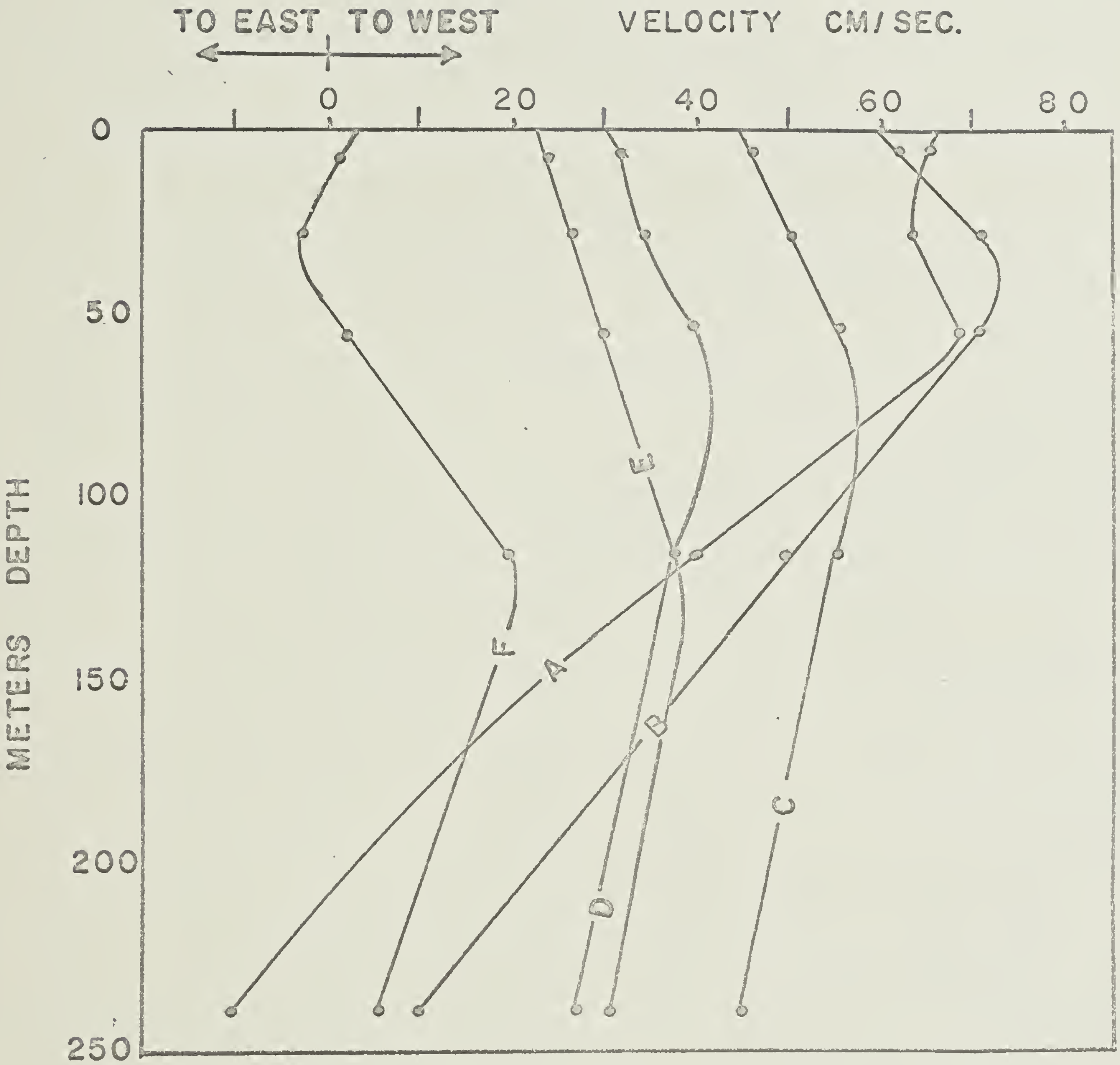
III. Current velocities in two-layered ocean

IV. Line strain for 12,000 foot depths

V. Parachute drogues in St. Lucia and St. Vincent Passages

VI. Parachute drogues in Southern Venezuela Basin

VII. Parachute drogue at anchor station #7



PILLSBURY
CURRENT PROFILES
EASTERN CARIBBEAN
PASSAGES
(After Model, 1950)

FIGURE 1

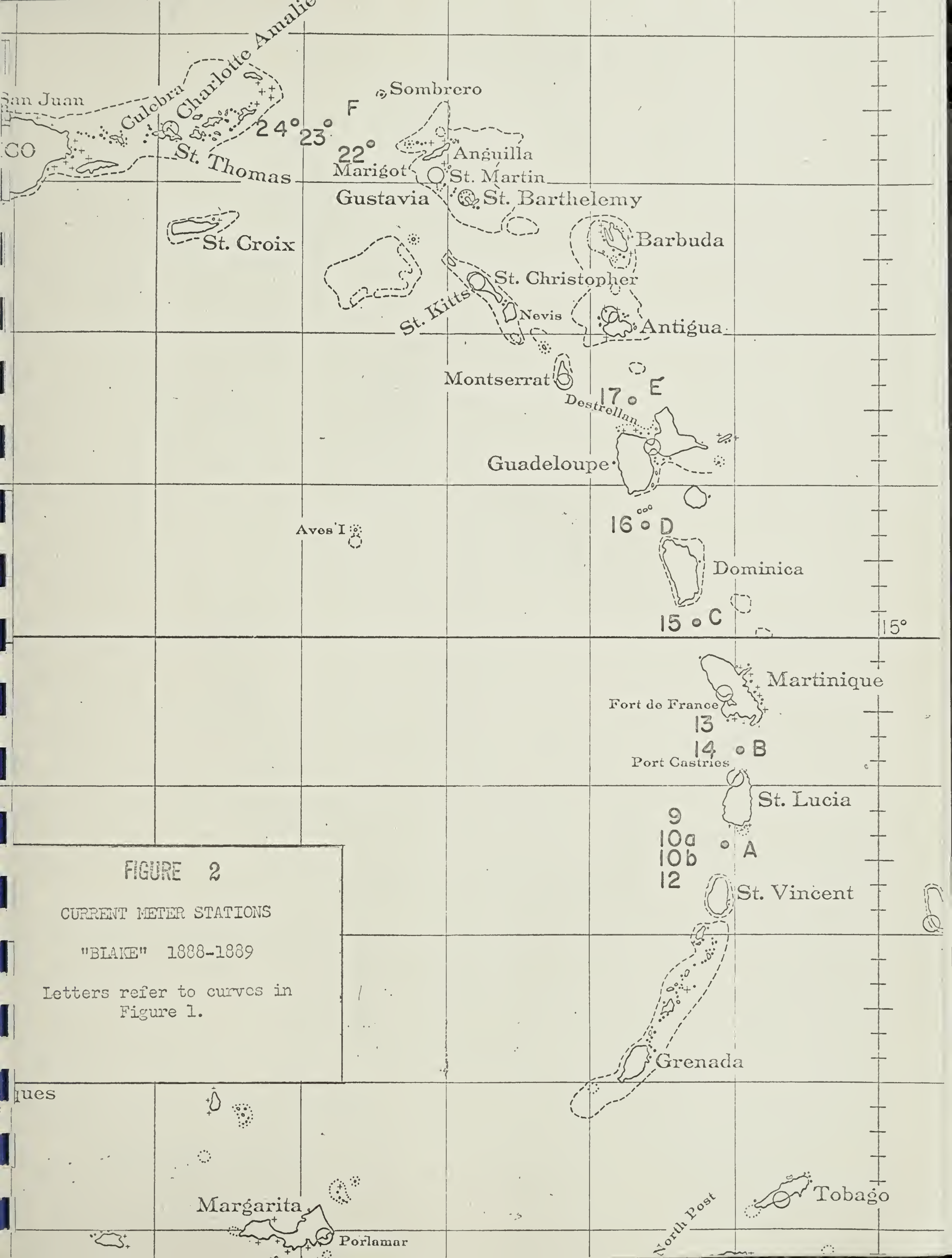


FIGURE 2

CURRENT METER STATIONS

"BLAKE" 1888-1889

Letters refer to curves in Figure 1.

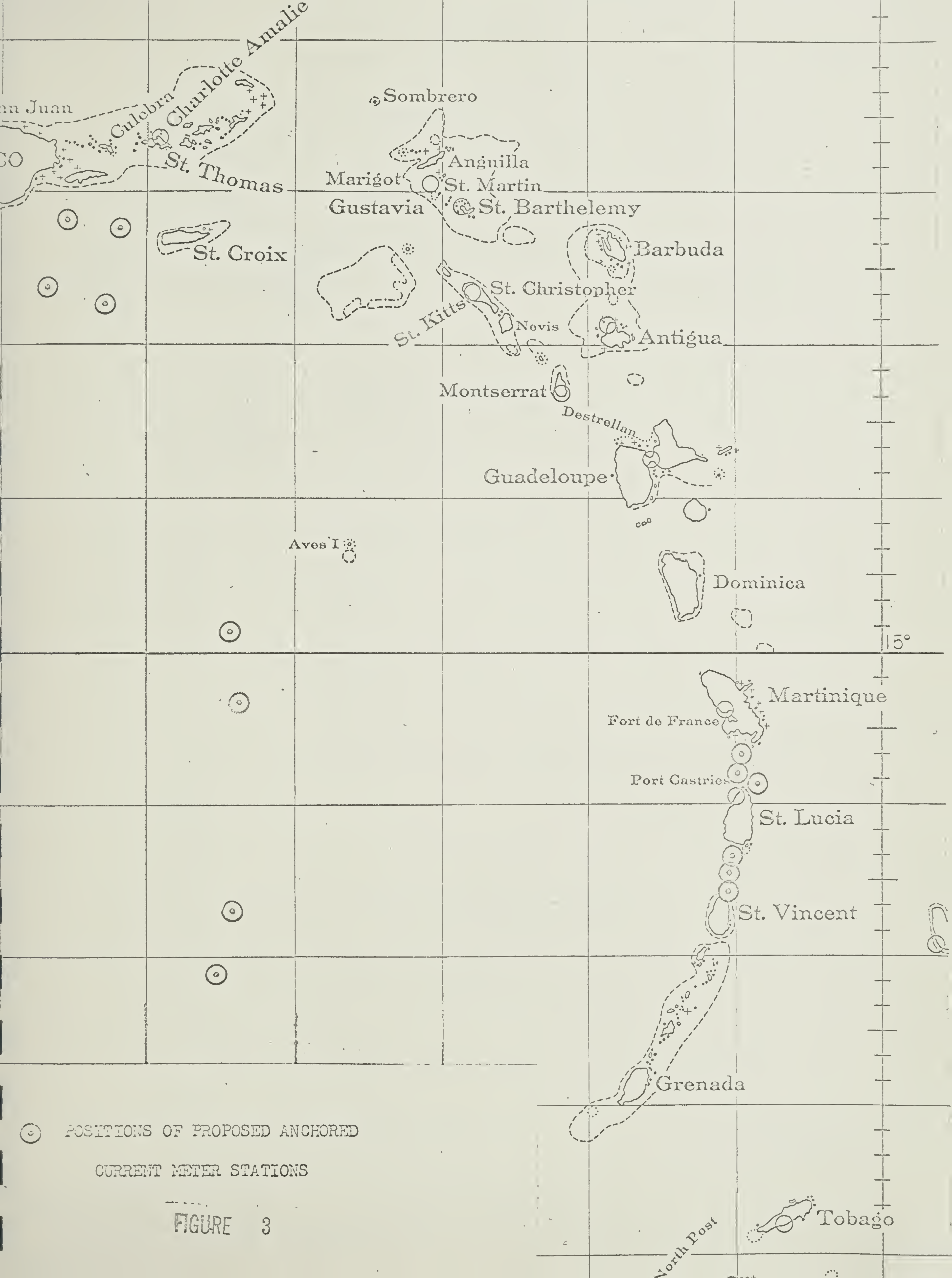

an Juan
CO
Culebra
Charlotte Amalie
St. Thomas
St. Croix
Sombrero
Anguilla
Marigot
St. Martin
Gustavia
St. Barthelemy
Barbuda
St. Christopher
St. Kitts
Novis
Antigua
Montserrat
Destrellan
Guadeloupe
Aves I
Dominica
15°
Martinique
Fort de France
Port Castries
St. Lucia
St. Vincent
Grenada
Tobago
North Post
POSITIONS OF PROPOSED ANCHORED CURRENT METER STATIONS

FIGURE 3

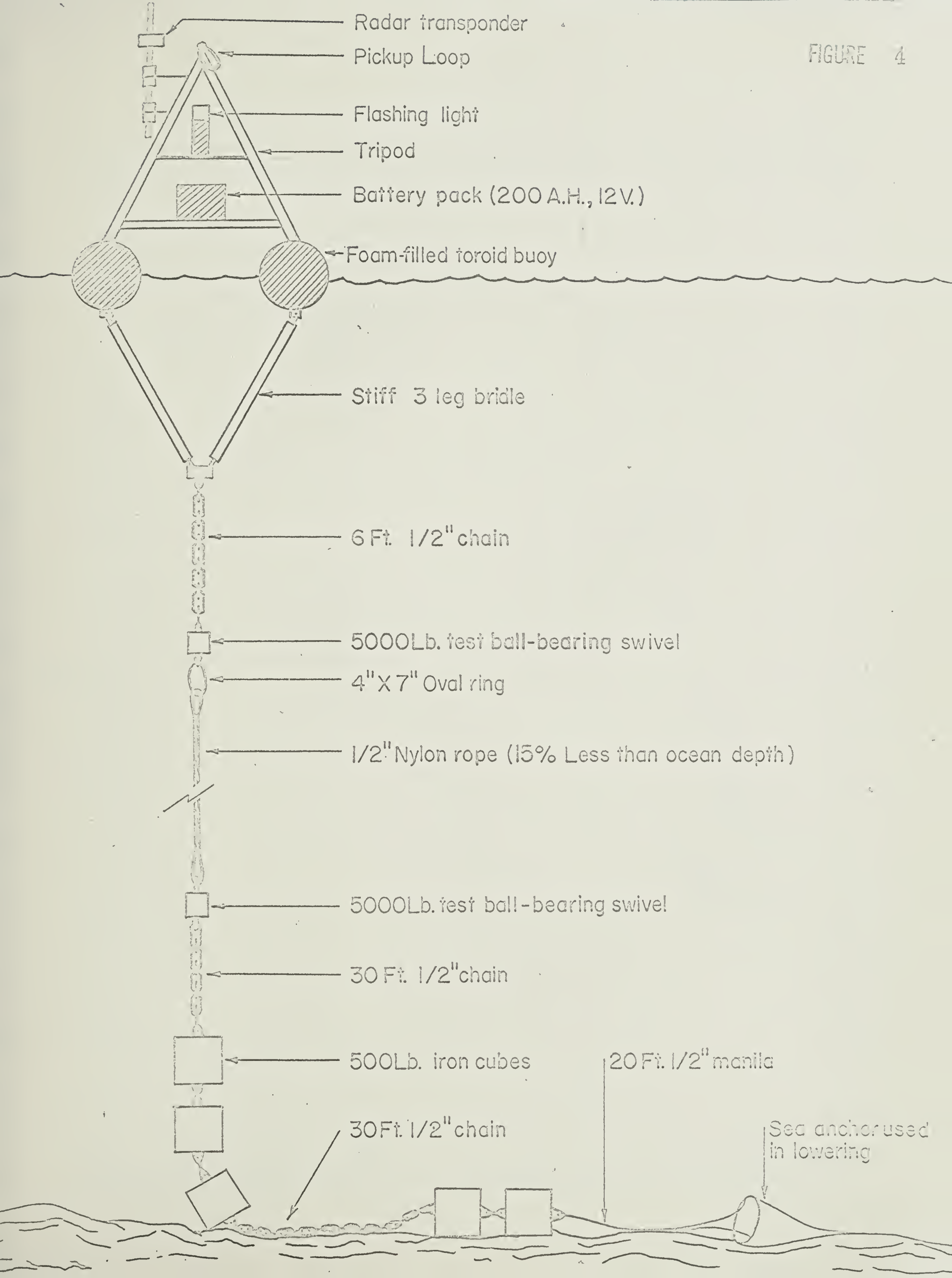


FIGURE 4

Radar transponder
Pickup Loop
Flashing light
Tripod
Battery pack (200 A.H., 12V.)
Foam-filled toroid buoy
Stiff 3 leg bridle
6 Ft. 1/2" chain
5000Lb. test ball-bearing swivel
4" X 7" Oval ring
1/2" Nylon rope (15% Less than ocean depth)
5000Lb. test ball-bearing swivel
30 Ft. 1/2" chain
500Lb. iron cubes
20 Ft. 1/2" manila
30 Ft. 1/2" chain
Sea anchor used in lowering

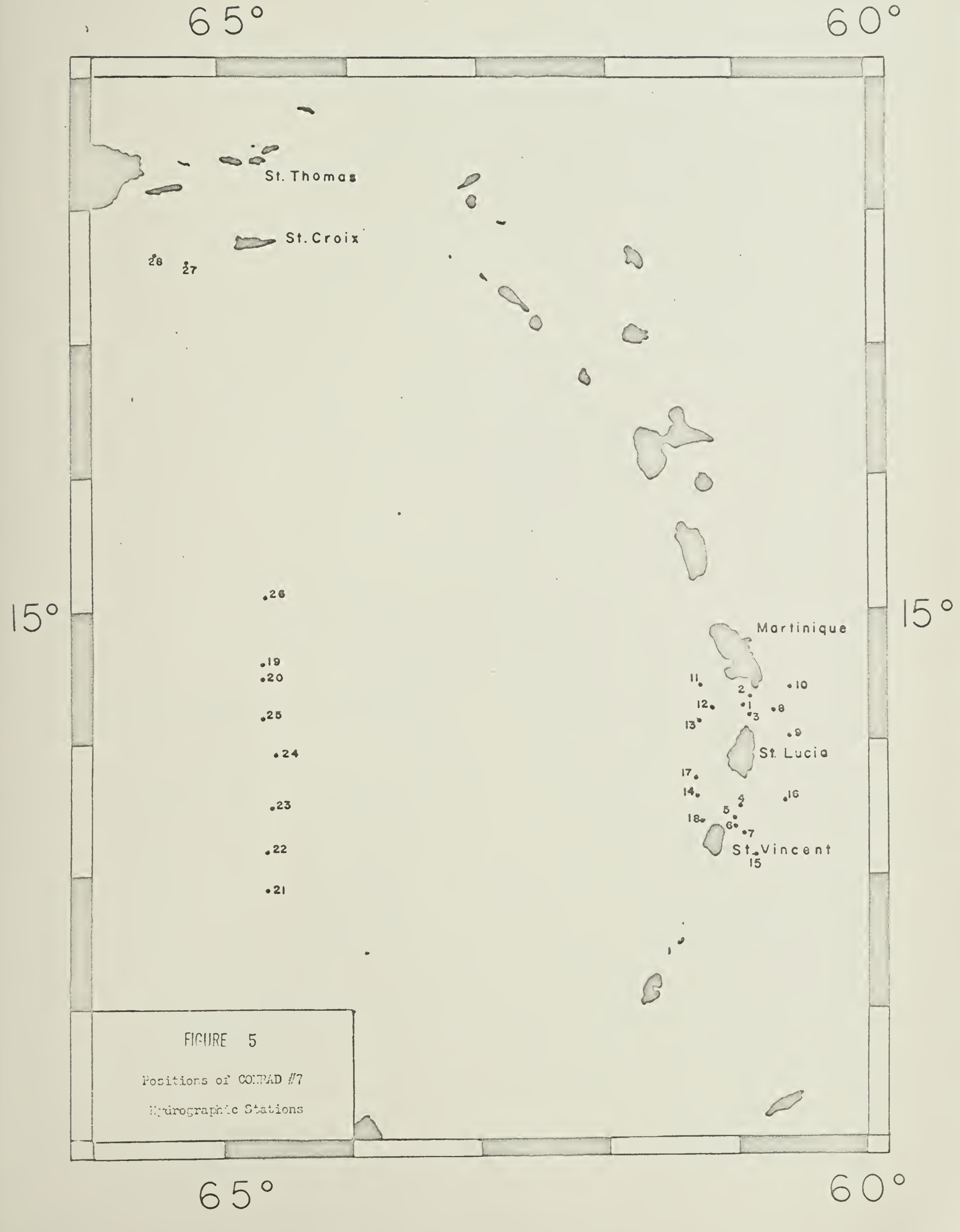


FIGURE 5

Positions of CONRAD #7 Hydrographic Stations

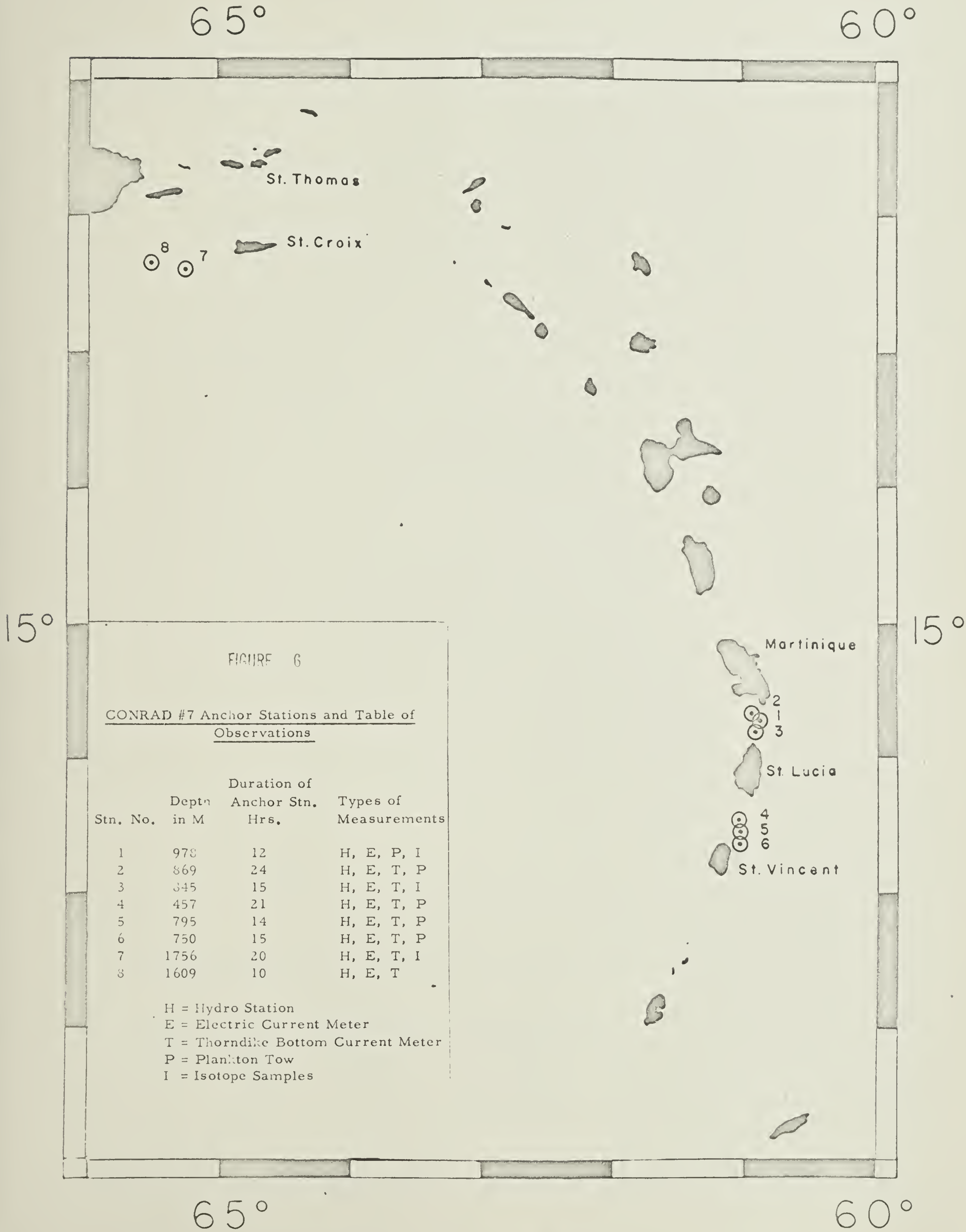


FIGURE 6

CONRAD #7 Anchor Stations and Table of Observations

Stn. No.	Depth in M	Duration of Anchor Stn. Hrs.	Types of Measurements
1	978	12	H, E, P, I
2	869	24	H, E, T, P
3	845	15	H, E, T, I
4	457	21	H, E, T, P
5	795	14	H, E, T, P
6	750	15	H, E, T, P
7	1756	20	H, E, T, I
8	1609	10	H, E, T

H = Hydro Station
E = Electric Current Meter
T = Thorndike Bottom Current Meter
P = Plankton Tow
I = Isotope Samples

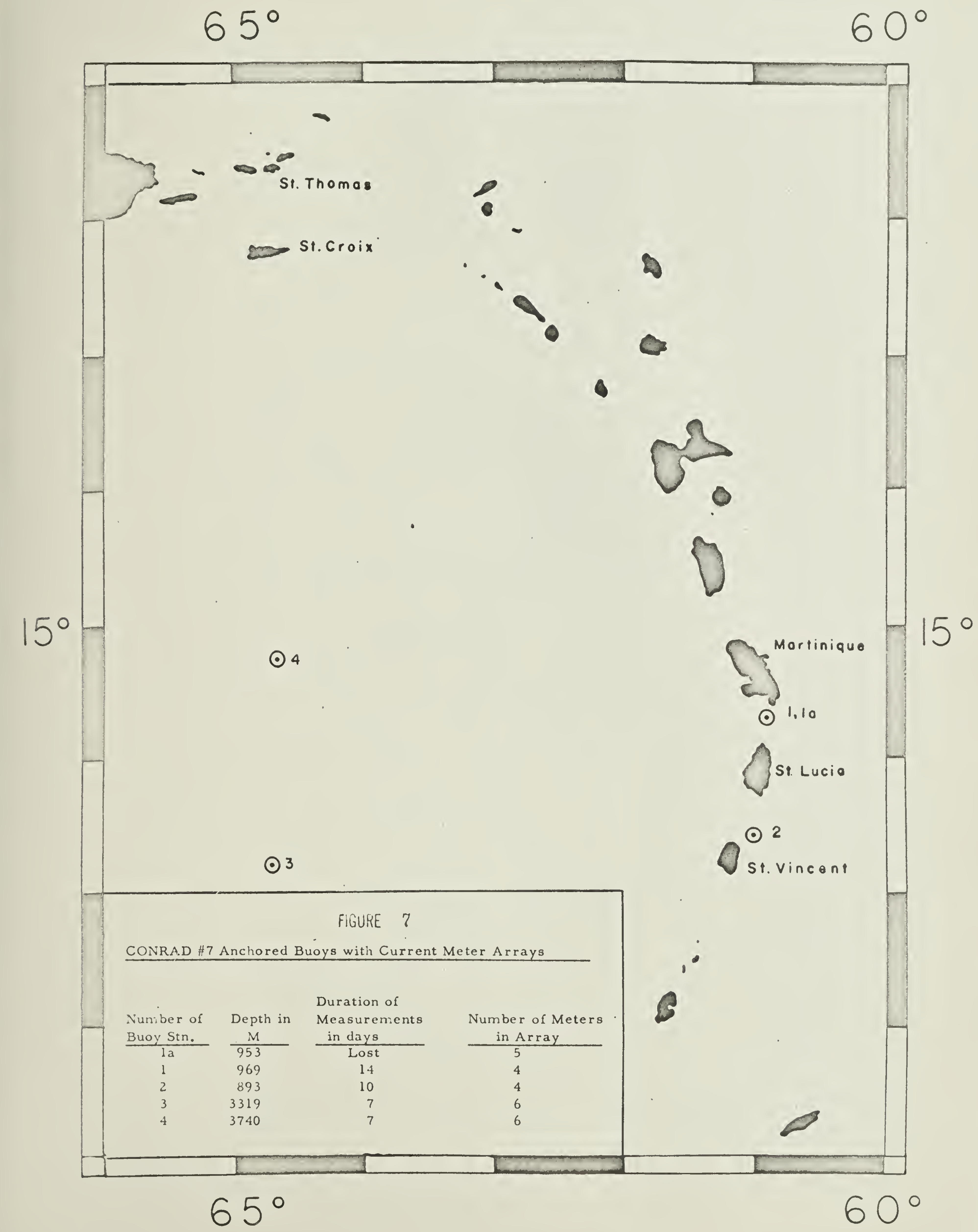


FIGURE 7

CONRAD #7 Anchored Buoys with Current Meter Arrays

Number of Buoy Stn.	Depth in M	Duration of Measurements in days	Number of Meters in Array
1a	953	Lost	5
1	969	14	4
2	893	10	4
3	3319	7	6
4	3740	7	6

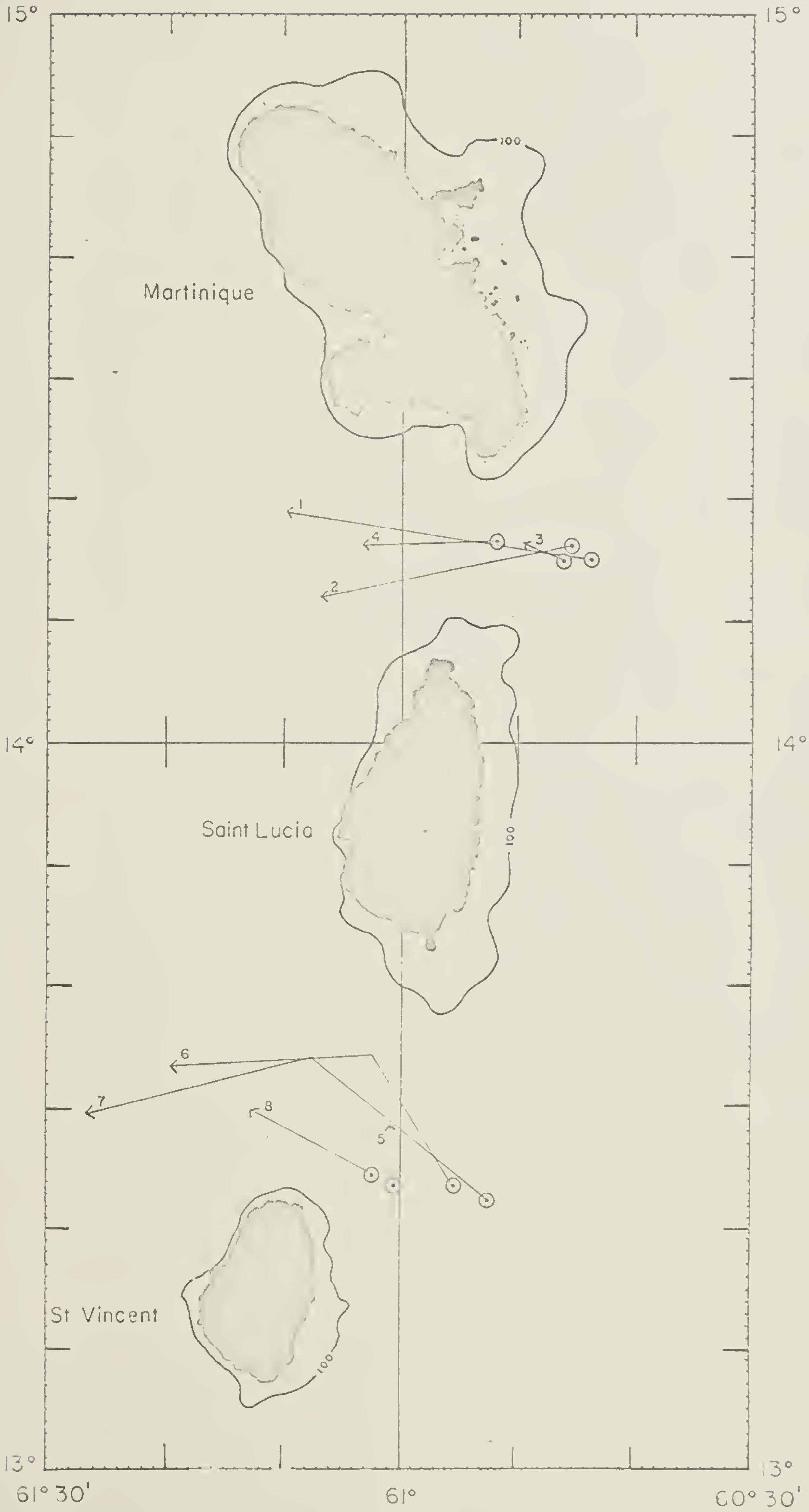
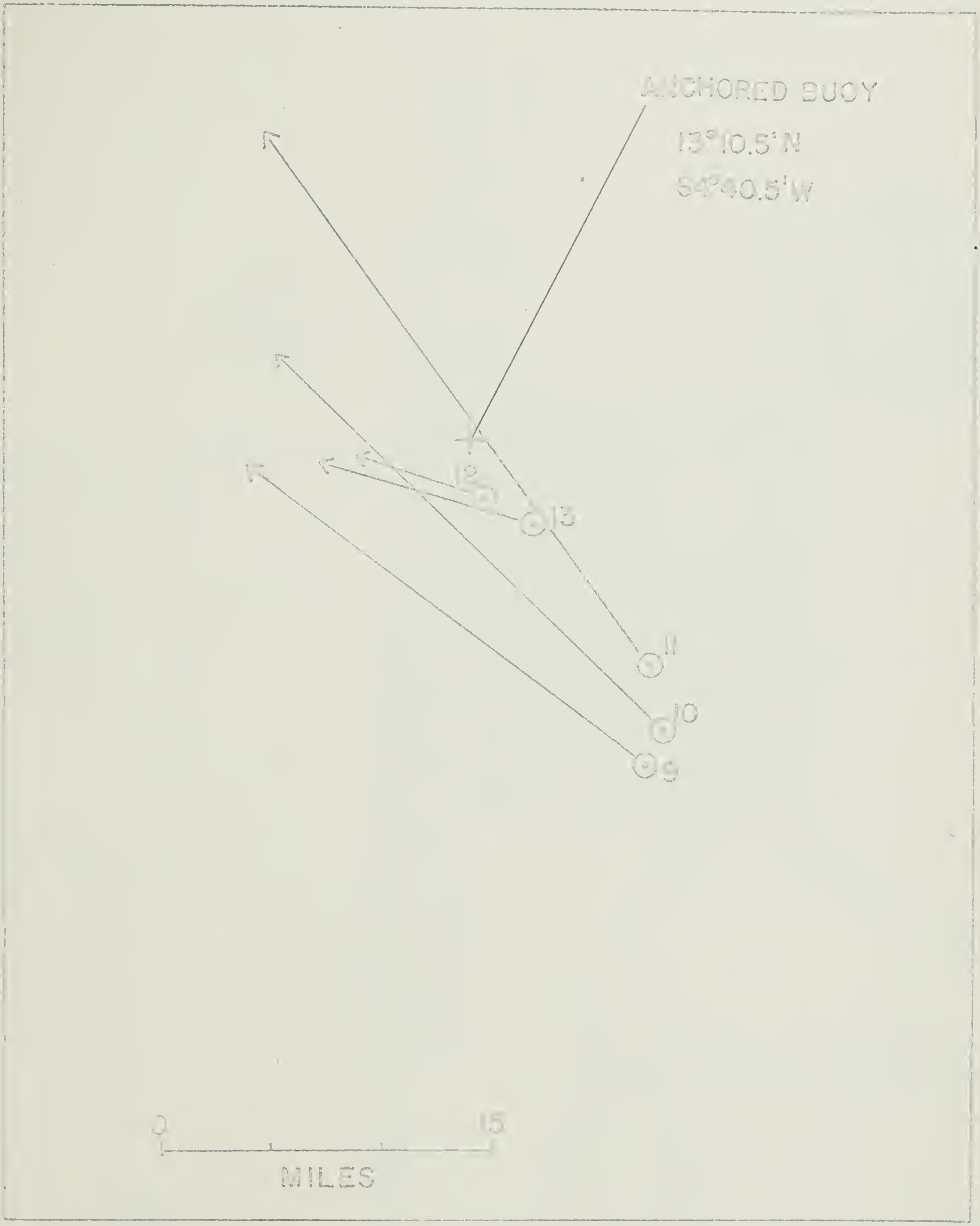


FIGURE 5

CONRAD #7 Parachute Drogues in St. Lucia and St. Vincent Passages

See Table V. for explanation

5 mi.



CONRAD #7 Parachute drogues in Southern Venezuela Basin

See Table VI for explanation

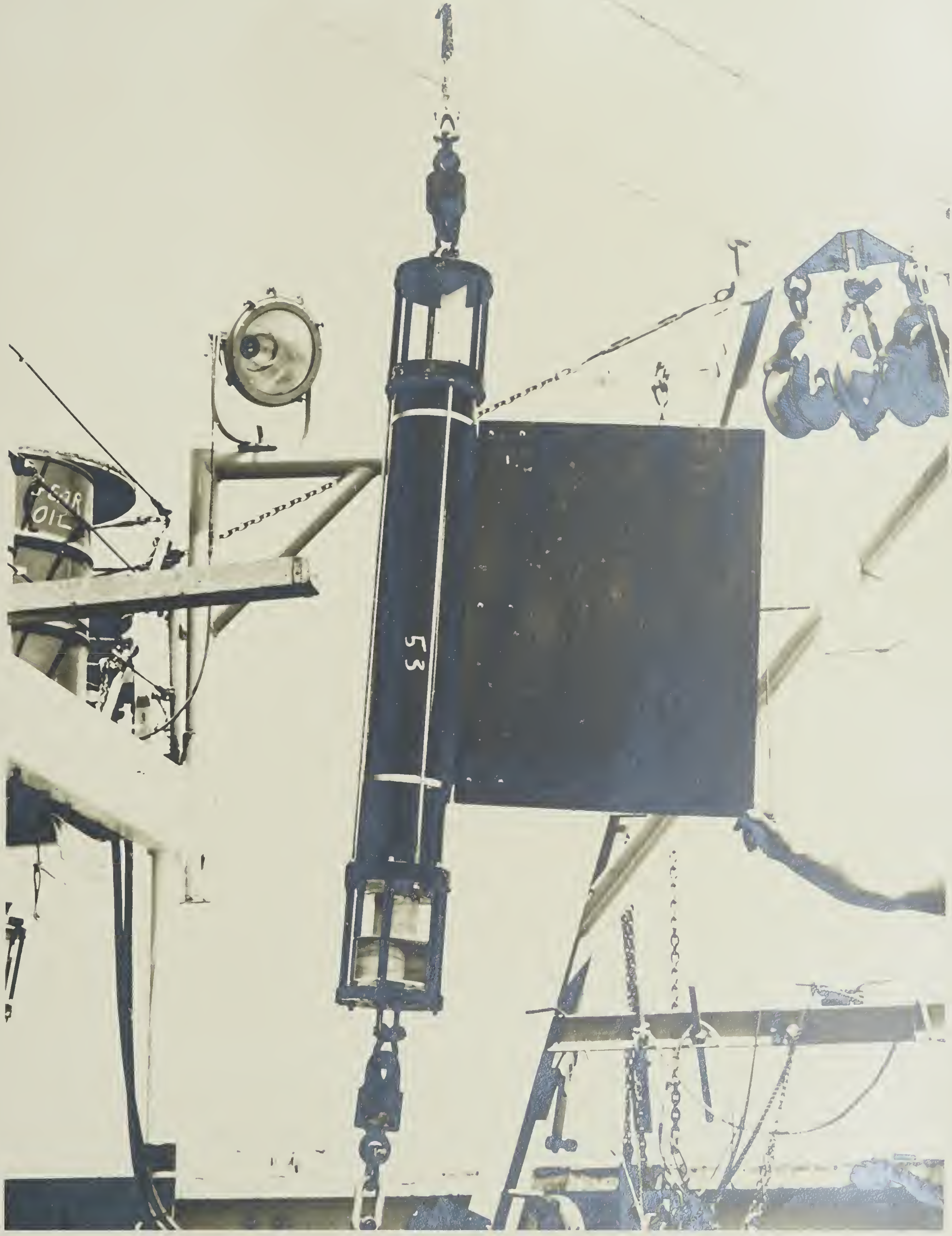
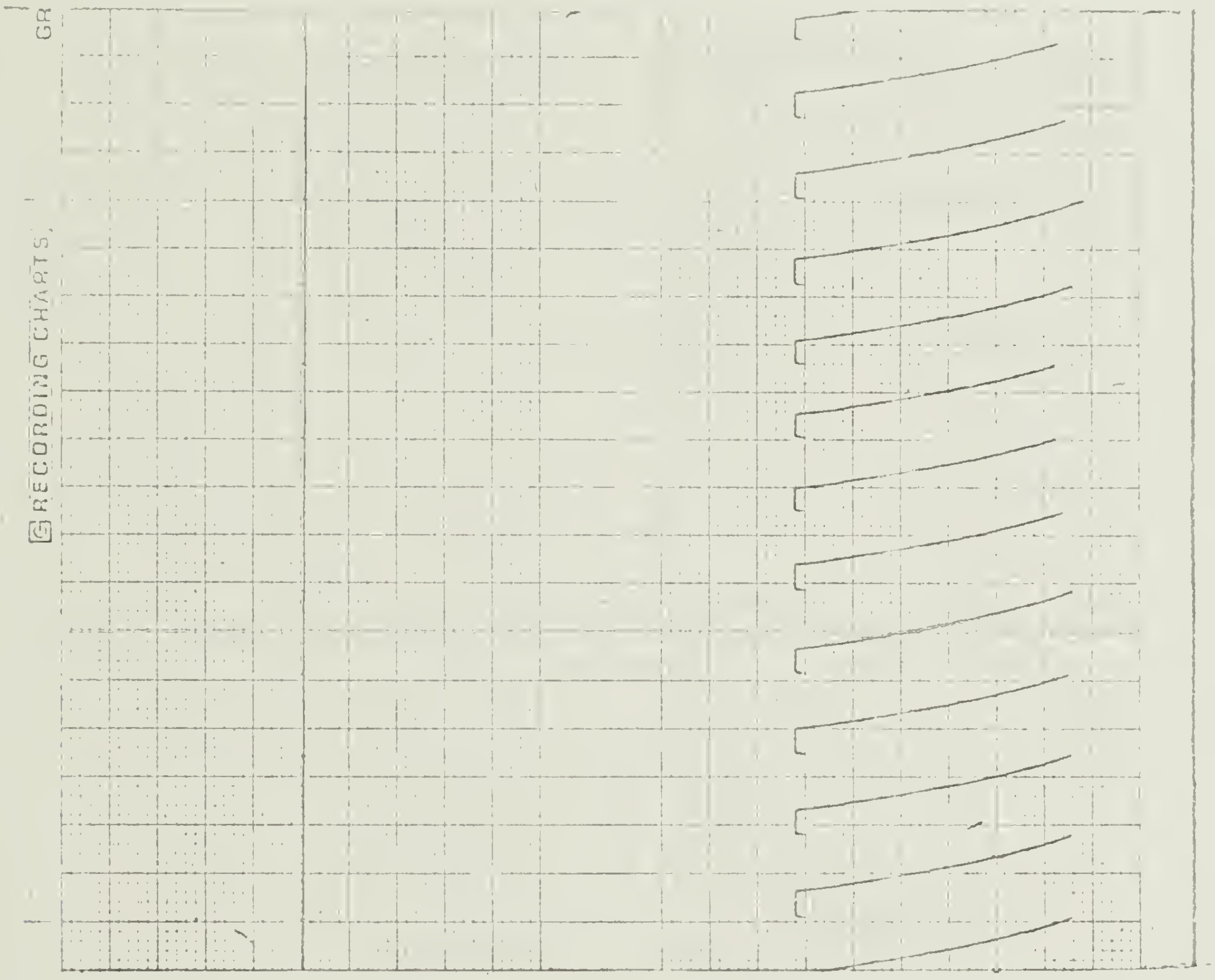


FIGURE 10



Direction Velocity

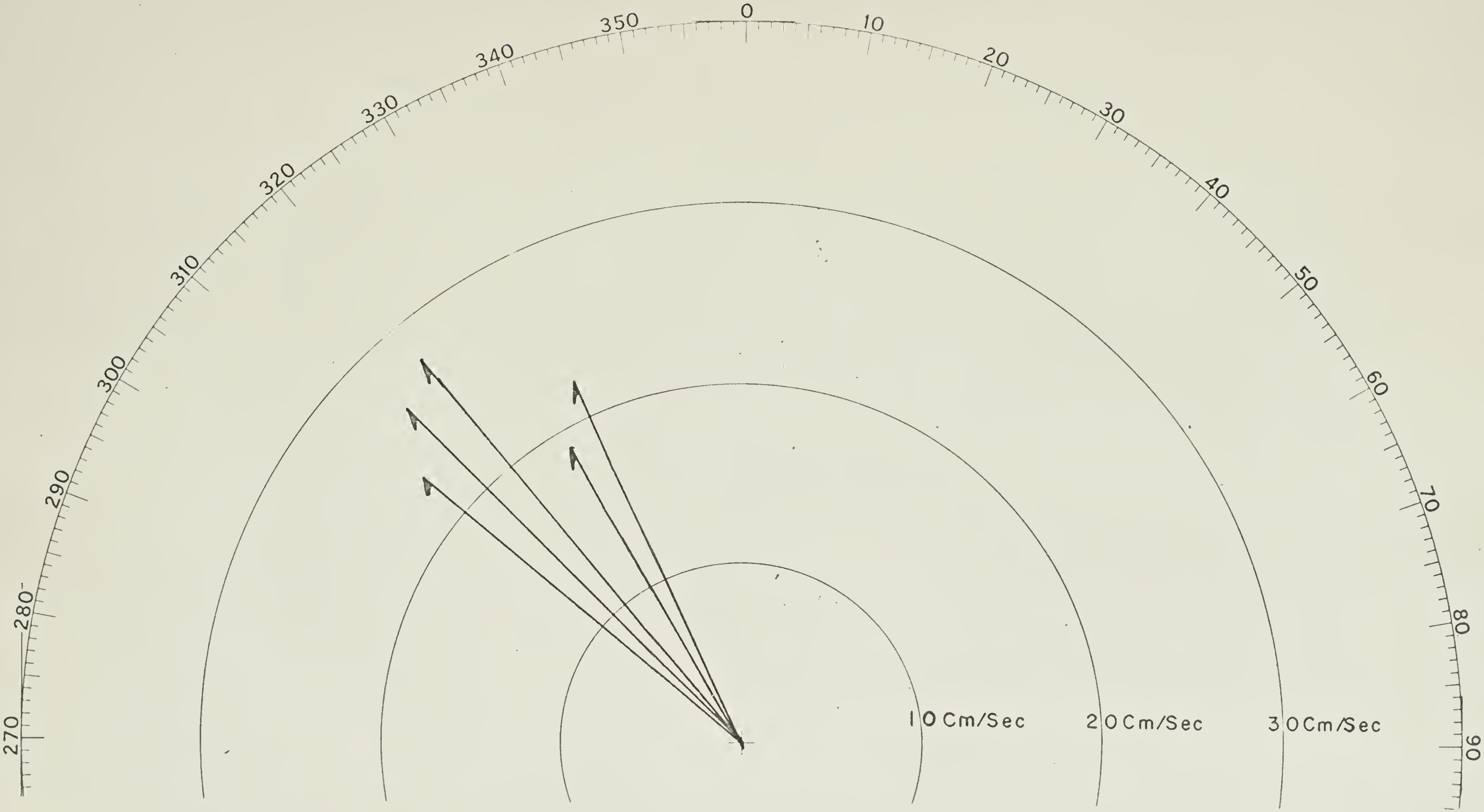
Segment of Deck recording Current Meter Record

CONRAD 7

19 September, 1963; Anchor Station #8
Lowering #2

Depth: 200 Fathoms

FIGURE 1.1



Bottom currents observed in the St. Lucia Channel during CONRAD #5 April, 1963. These observations were made with the Thorndike Photographic Bottom Current meter. Eight more stations of this kind were made during CONRAD #7.

FIGURE 12

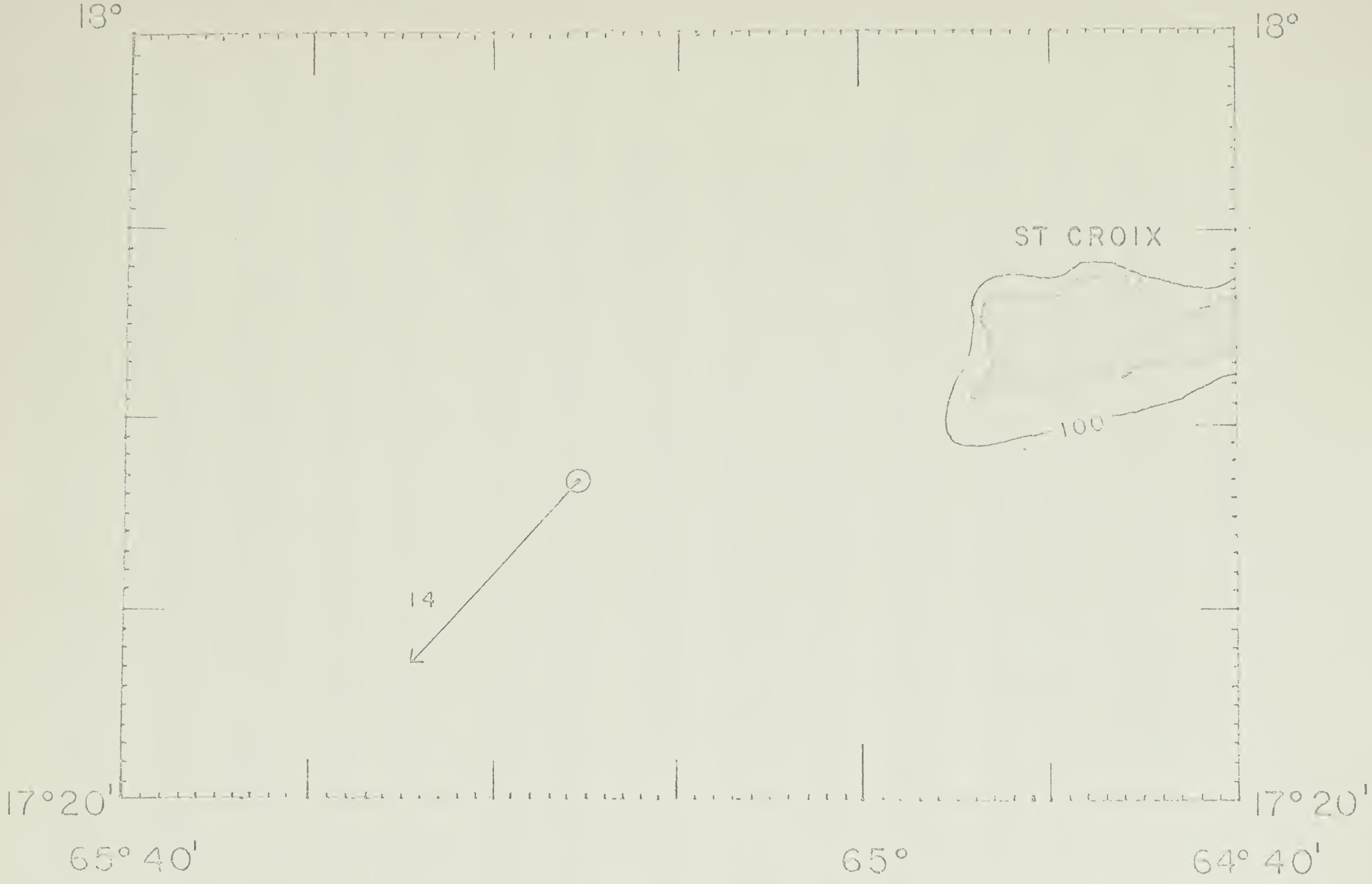


FIGURE 1 3

CONRAD #7 Parachute Drogue at anchor station #7

See Table VII for explanation

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